Chapter 1 Topics

- Reasons for Studying Concepts of Programming Languages
- Programming Domains
- Language Evaluation Criteria
- Influences on Language Design
- Language Categories
- Language Design Trade-Offs
- Implementation Methods
- Programming Environments

Copyright © 2018 Pearson. All rights reserved.

Reasons for Studying Concepts of Programming Languages

- Increased ability to express ideas
- Improved background for choosing appropriate languages
- Increased ability to learn new languages
- Better understanding of the significance of implementation
- Better use of languages that are already known
- Overall advancement of computing

Copyright © 2018 Pearson. All rights reserved.

Programming Domains

- Scientific applications
  - Large numbers of floating point computations; use of arrays
  - Fortran
- Business applications
  - Produce reports, use decimal numbers and characters
  - COBOL
- Artificial intelligence
  - Symbols rather than numbers manipulated; use of linked lists
  - LISP
- Systems programming
  - Need efficiency because of continuous use
  - C
- Web Software
  - Eclectic collection of languages: markup (e.g., HTML), scripting (e.g., PHP), general-purpose (e.g., Java)

Copyright © 2018 Pearson. All rights reserved.

Language Evaluation Criteria

- **Readability**: the ease with which programs can be read and understood
- **Writability**: the ease with which a language can be used to create programs
- **Reliability**: conformance to specifications (i.e., performs to its specifications)
- **Cost**: the ultimate total cost

Copyright © 2018 Pearson. All rights reserved.

Evaluation Criteria: Readability

- Overall simplicity
  - A manageable set of features and constructs
  - Minimal feature multiplicity
  - Minimal operator overloading
- Orthogonality
  - A relatively small set of primitive constructs can be combined in a relatively small number of ways
  - Every possible combination is legal
- Data types
  - Adequate predefined data types
- Syntax considerations
  - Identifier forms: flexible composition
  - Special words and methods of forming compound statements
  - Form and meaning: self-descriptive constructs, meaningful keywords

Copyright © 2018 Pearson. All rights reserved.

Evaluation Criteria: Writability

- Simplicity and orthogonality
  - Few constructs, a small number of primitives, a small set of rules for combining them
- Support for abstraction
  - The ability to define and use complex structures or operations in ways that allow details to be ignored
- Expressivity
  - A set of relatively convenient ways of specifying operations
  - Strength and number of operators and predefined functions

Copyright © 2018 Pearson. All rights reserved.

Evaluation Criteria: Reliability

- Type checking
  - Testing for type errors
- Exception handling
  - Intercept run-time errors and take corrective measures
- Aliasing
  - Presence of two or more distinct referencing methods for the same memory location
- Readability and writability
  - A language that does not support “natural” ways of expressing an algorithm will require the use of “unnatural” approaches, and hence reduced reliability

Copyright © 2018 Pearson. All rights reserved.

Evaluation Criteria: Cost

- Training programmers to use the language
- Writing programs (closeness to particular applications)
- Executing programs
- Reliability: poor reliability leads to high costs
- Maintaining programs

Copyright © 2018 Pearson. All rights reserved.

Evaluation Criteria: Others

- Portability
  - The ease with which programs can be moved from one implementation to another
- Generality
  - The applicability to a wide range of applications
- Well-definedness
  - The completeness and precision of the language's official definition

Copyright © 2018 Pearson. All rights reserved.

Influences on Language Design

- Computer Architecture
  - Languages are developed around the prevalent computer architecture, known as the *von Neumann* architecture
- Program Design Methodologies
  - New software development methodologies (e.g., object-oriented software development) led to new programming paradigms and by extension, new programming languages

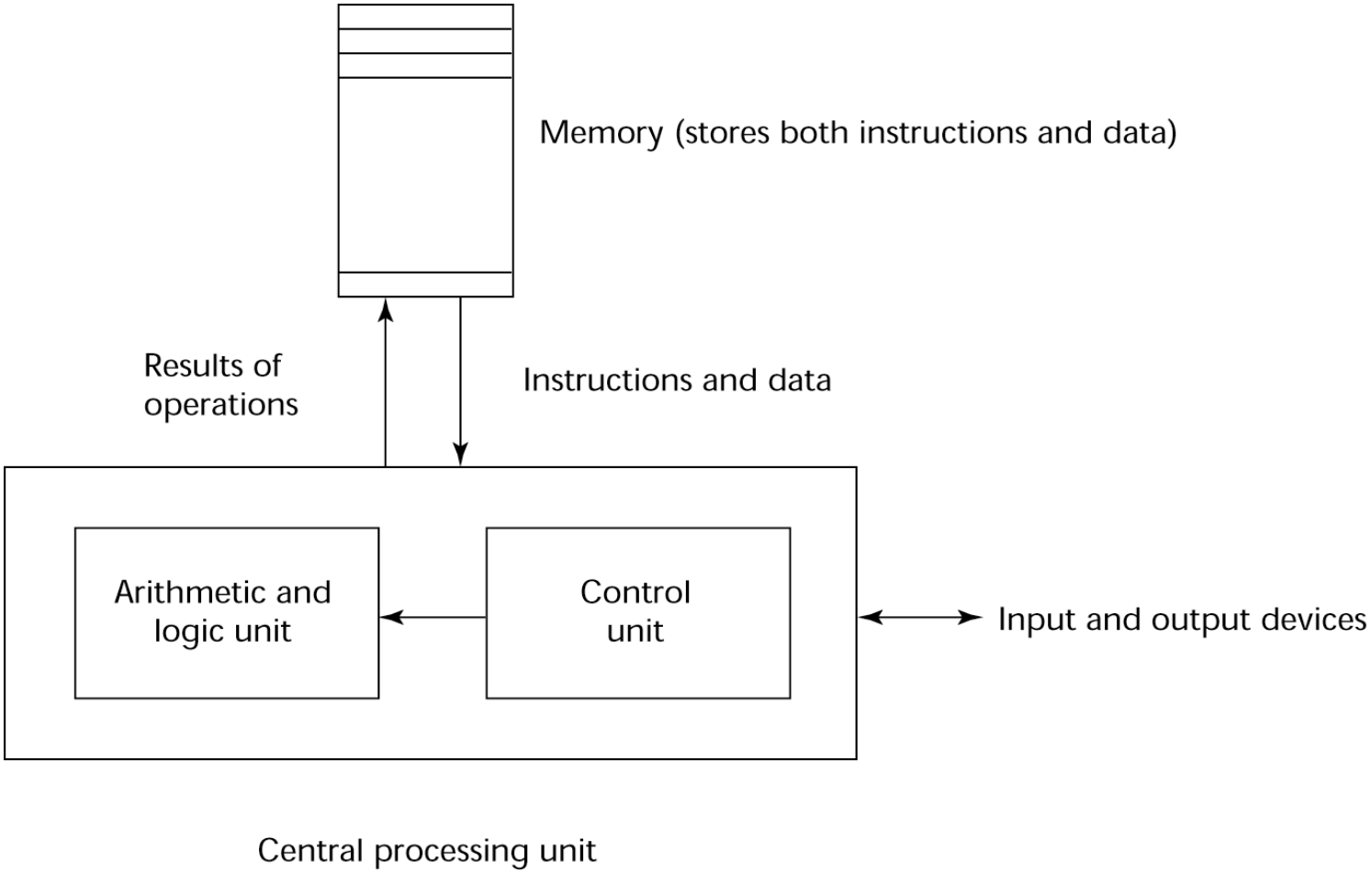
Copyright © 2018 Pearson. All rights reserved.

Computer Architecture Influence

- Well-known computer architecture: Von Neumann
- Imperative languages, most dominant, because of von Neumann computers
  - Data and programs stored in memory
  - Memory is separate from CPU
  - Instructions and data are piped from memory to CPU
  - Basis for imperative languages
    - Variables model memory cells
    - Assignment statements model piping
    - Iteration is efficient

Copyright © 2018 Pearson. All rights reserved.

The von Neumann Architecture



Copyright © 2018 Pearson. All rights reserved.

The von Neumann Architecture

- Fetch-execute-cycle (on a von Neumann architecture computer)

```
initialize the program counter
repeat forever
  fetch the instruction pointed by the counter
  increment the counter
  decode the instruction
  execute the instruction
end repeat
```

Copyright © 2018 Pearson. All rights reserved.

Programming Methodologies Influences

- 1950s and early 1960s: Simple applications; worry about machine efficiency
- Late 1960s: People efficiency became important; readability, better control structures
  - structured programming
  - top-down design and step-wise refinement
- Late 1970s: Process-oriented to data-oriented
  - data abstraction
- Middle 1980s: Object-oriented programming
  - Data abstraction + inheritance + polymorphism

Copyright © 2018 Pearson. All rights reserved.

Language Categories

- Imperative
  - Central features are variables, assignment statements, and iteration
  - Include languages that support object-oriented programming
  - Include scripting languages
  - Include the visual languages
  - Examples: C, Java, Perl, JavaScript, Visual BASIC .NET, C++
- Functional
  - Main means of making computations is by applying functions to given parameters
  - Examples: LISP, Scheme, ML, F#
- Logic
  - Rule-based (rules are specified in no particular order)
  - Example: Prolog
- Markup/programming hybrid
  - Markup languages extended to support some programming
  - Examples: JSTL, XSLT

Copyright © 2018 Pearson. All rights reserved.

Language Design Trade-Offs

- Reliability vs. cost of execution
  - Example: Java demands all references to array elements be checked for proper indexing, which leads to increased execution costs
- Readability vs. writability

  Example: APL provides many powerful operators (and a large number of new symbols), allowing complex computations to be written in a compact program but at the cost of poor readability
- Writability (flexibility) vs. reliability
  - Example: C++ pointers are powerful and very flexible but are unreliable

Copyright © 2018 Pearson. All rights reserved.

Implementation Methods

- Compilation
  - Programs are translated into machine language; includes (Justi-in-time Compilation Systems) JIT systems
  - Use: Large commercial applications. Example C,
  - C source code → Machine code → Run

- Pure Interpretation
  - Programs are interpreted by another program known as an interpreter
  - Use: Small programs or when efficiency is not an issue

  Example: Python source → Python interpreter → Execution

Copyright © 2018 Pearson. All rights reserved.

Implementation Methods

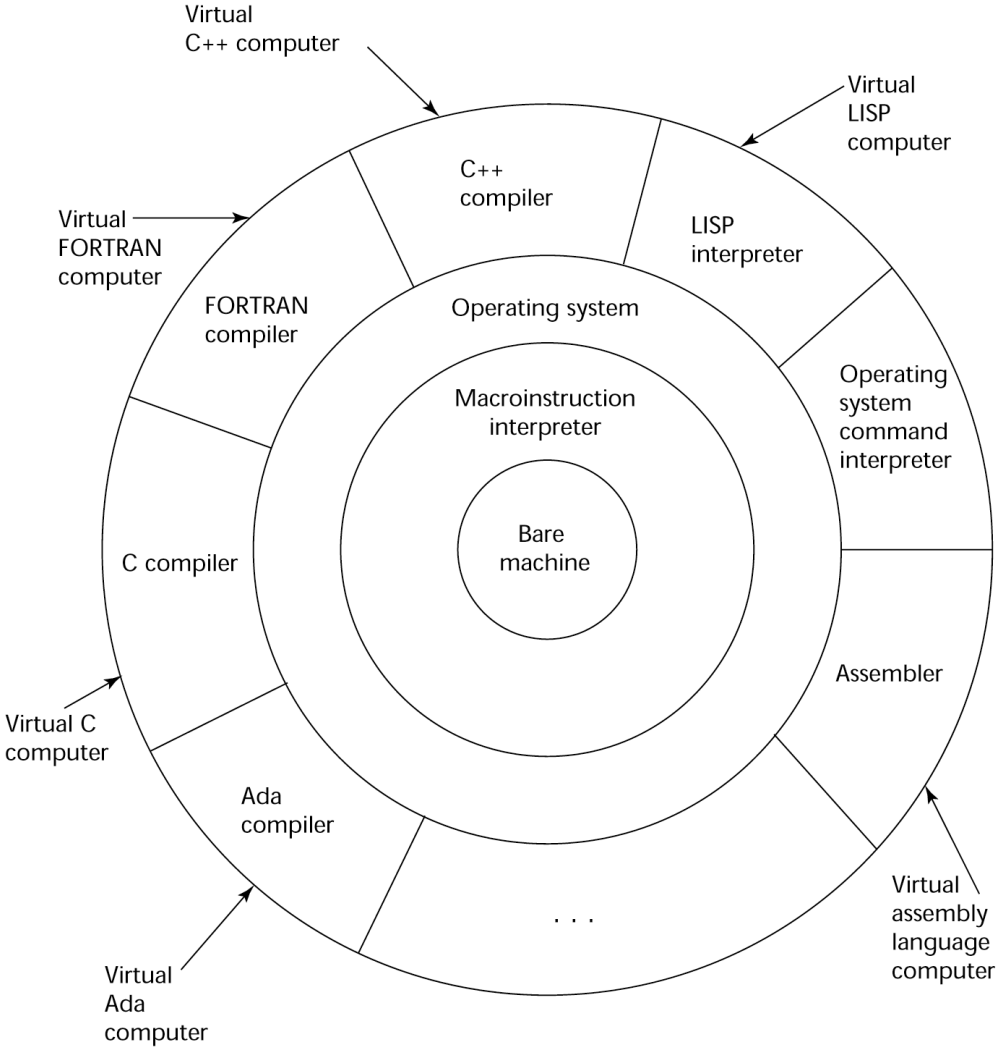
- Hybrid Implementation Systems
  - A compromise between compilers and pure interpreters
  - Use: Small and medium systems when efficiency is not the first concern

- JavaScript source
- ↓
- Parse + Bytecode
- ↓
- Interpret first
- ↓
- JIT compile hot code (optional)

Copyright © 2018 Pearson. All rights reserved.

Layered View of Computer

The operating system and language implementation are layered over machine interface of a computer



Copyright © 2018 Pearson. All rights reserved.

Compilation

- Translate high-level program (source language) into machine code (machine language)
- Slow translation (Many checks, happens once) , fast execution (runs in machine code)

- Source Program → Compiler → Machine Code → Execute

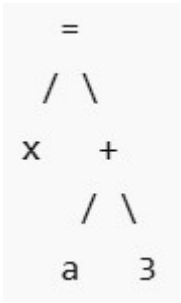
- Compilation process has several phases:

  - lexical analysis: converts characters in the source program into lexical units (tokens), x = a + 3 ->IDENTIFIER(x) ASSIGN IDENTIFIER(a) PLUS INTEGER(3) SEMICOLON

Copyright © 2018 Pearson. All rights reserved.

Compilation

- syntax analysis: transforms lexical units into *parse trees* which represent the syntactic structure of the program, checks grammar, etc
- x = a + 3;



  - Semantics analysis (Checks **meaning**, not structure) : generate intermediate code
    - x = "hello"; // if x is an integer → semantic error
    - y = z + 1; // if z is undeclared → semantic error
  - code generation: machine code is generated (goes from intermediate code generation, machine independent t1 = a + 3, x = t1 to LOAD a
  - ADD 3, STORE x (CPU understandable, architecture dependent)

Copyright © 2018 Pearson. All rights reserved.

Additional Compilation Terminologies

- **Load module or place in memory** (executable image): the user (source code) and system code (libraries, runtime support, startup routines) together, *everything the CPU needs* to run your program.

- **Linking and loading**: the process of collecting system program units and linking them to a user program

Copyright © 2018 Pearson. All rights reserved.

Von Neumann Bottleneck

- The connection speed between a computer's memory and its processor determines the speed of the computer
- Program instructions often can be executed much faster than the speed of the connection; the connection speed thus results in a *bottleneck*
- Known as the *von Neumann bottleneck*; it is the primary limiting factor in the speed of computers

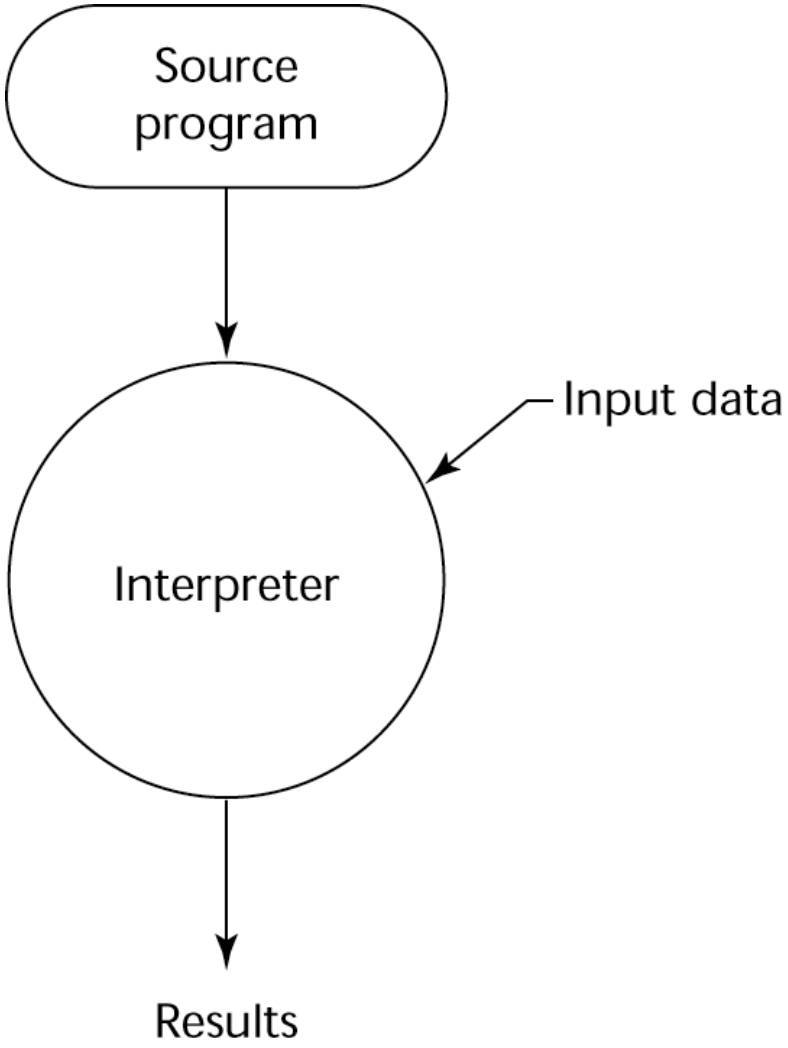
Copyright © 2018 Pearson. All rights reserved.

Pure Interpretation

- No translation
- Easier implementation of programs (run-time errors can easily and immediately be displayed)
- Slower execution (10 to 100 times slower than compiled programs)
- Often requires more space
- Now rare for traditional high-level languages
- Significant comeback with some Web scripting languages (e.g., JavaScript, PHP)

Copyright © 2018 Pearson. All rights reserved.

Pure Interpretation Process



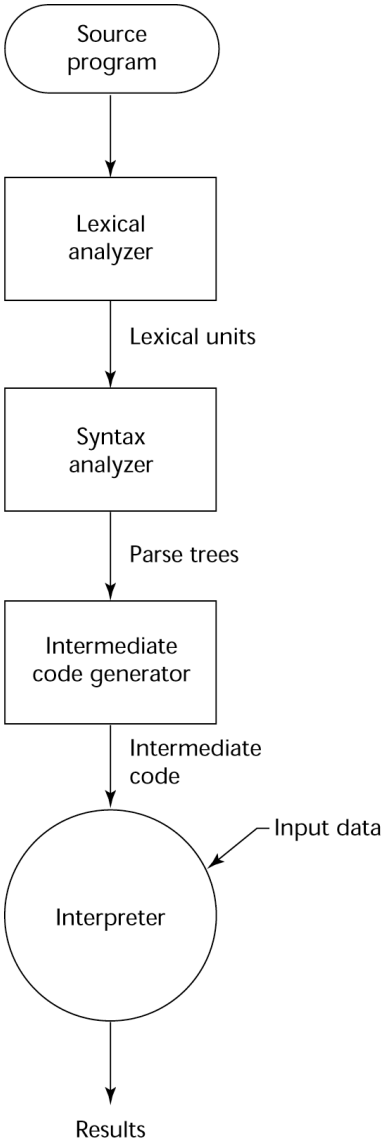
Copyright © 2018 Pearson. All rights reserved.

Hybrid Implementation Systems

- A compromise between compilers and pure interpreters
- A high-level language program is translated to an intermediate language that allows easy interpretation
- Faster than pure interpretation
- Examples
  - Perl programs are partially compiled to detect errors before interpretation
  - Initial implementations of Java were hybrid; the intermediate form, *byte code*, provides portability to any machine that has a byte code interpreter and a run-time system (together, these are called *Java Virtual Machine*)

Copyright © 2018 Pearson. All rights reserved.

Hybrid Implementation Process



Copyright © 2018 Pearson. All rights reserved.

Just-in-Time Implementation Systems

- Initially translate programs to an intermediate language
- Then compile the intermediate language of the subprograms into machine code when they are called

- JIT systems are widely used for Java programs
- .NET languages are implemented with a JIT system
- In essence, JIT systems are delayed compilers

Copyright © 2018 Pearson. All rights reserved.

Preprocessors

- Preprocessor macros (instructions) are commonly used to specify that code from another file is to be included

- A preprocessor processes a program immediately before the program is compiled to expand embedded preprocessor macros
- A well-known example: C preprocessor
  - expands #include, #de
  - Source Code
  - ↓
  - Preprocessor ← (macros expanded here)
  - ↓
  - Compiler (lexical, syntax, semantic analysis)
  - ↓
  - Object

Copyright © 2018 Pearson. All rights reserved.

Programming Environments

- A collection of tools used in software development
- UNIX
  - An older operating system and tool collection
  - Nowadays often used through a GUI (e.g., CDE, KDE, or GNOME) that runs on top of UNIX
- Microsoft Visual Studio.NET
  - A large, complex visual environment
- Used to build Web applications and non-Web applications in any .NET language
- NetBeans
  - Related to Visual Studio .NET, except for applications in Java

Copyright © 2018 Pearson. All rights reserved.

Summary

- The study of programming languages is valuable for a number of reasons:
  - Increase our capacity to use different constructs
  - Enable us to choose languages more intelligently
  - Makes learning new languages easier
- Most important criteria for evaluating programming languages include:
  - Readability, writability, reliability, cost
- Major influences on language design have been machine architecture and software development methodologies
- The major methods of implementing programming languages are: compilation, pure interpretation, and hybrid implementation

Copyright © 2018 Pearson. All rights reserved.